MOMENTUM LAB
ADVANCED SAIL CAR

What’s momentum, and how does it affect collisions? Crash some cars to find out!

LAB SUPPLIES

TeacherGeek Supplies

2 Sail Cars (no sails)
1 Dowel 30 cm (12 in)
2 Blocks
Multi-Cutter

Other Supplies

• Scale grams (0.1 oz)
• Tape
• 1 Weight 100-200 g (4-7 oz)
• 2 velocity sensors
• 1 velocity sensor & 2 magnets
(to make the cars stick together on impact)

For recommended sensors, see p. 3.

BUILD A RAM

Build a ram for one of your cars to get more accurate collision data.

1. Cut an 8 cm (3 in) dowel.
2. Wiggle or tap the cut dowel into a block.
3. Push or tap another block onto the dowel, as shown.
4. Cut two 3 cm (1 in) dowels.
5. Push the dowels into the block, as shown, to finish your ram.

Check out our lab set-up videos by scanning the QR Code or going to teachergeek.com/sailcar

Name: ____________________________
**WHAT’S MOMENTUM**

*Momentum* is how difficult it is to stop a moving object. It is based on how quickly an object is moving and how much mass it has.

This car has **little momentum** because it has little mass or velocity.

This car has **more momentum** because it has more mass and velocity.

**Calculating Momentum**

Momentum is typically represented by the letter \( p \). To calculate momentum, multiply mass and velocity.

\[
p = mv
\]

Momentum is a vector quantity – it has both magnitude and direction. The direction of the momentum is the direction of the velocity.

Momentum has units of \( kg \times m/s \).

**Example**

A 0.1 kg car is traveling East at 3 m/s.

\[
\begin{align*}
m &= 0.1 \text{ kg} \\
\end{align*}
\]

\[
\begin{align*}
p &= mv \\
&= (0.1 \text{ kg}) \times (3 \text{ m/s East}) \\
p &= 0.3 \text{ kg} \times \text{m/s East}
\end{align*}
\]
What happens to momentum during a collision?

1. **Push the car with the ram into the other car.**

   - **Striking Car**
   - **Car Being Struck**

   ![Image of cars colliding]

1. **How did the collision affect the momentum of the striking car?** Did momentum increase, decrease, or stay the same? Explain.

   ___________________________________
   ___________________________________
   ___________________________________
   ___________________________________
   ___________________________________

1. **How did the collision affect the momentum of the car being struck?** Explain.

   ___________________________________
   ___________________________________
   ___________________________________
   ___________________________________
   ___________________________________

**ADD SENSORS**

**Option A: One Sensor and Magnets**

Set up the sensor to measure the velocity of the striking car. Be careful to keep the magnets away from the sensor and all other electronic devices.

- **Recommended:** PocketLab
- **Recommended:** Ultrasonic or Infrared
- **Avoid:** PocketLab
- **Avoid:** Photogates

**Option B: Two Sensors**

Set up your sensors to measure the velocity of each car.

- **Recommended:** Ultrasonic or Infrared
- **Avoid:** Photogates

How did the collision affect the momentum of the striking car? Did momentum increase, decrease, or stay the same? Explain.

_________________________________
_________________________________
_________________________________
_________________________________
_________________________________

Create a hypothesis about what happens to momentum during a collision.

_________________________________
_________________________________
_________________________________
_________________________________
_________________________________

How did the collision affect the momentum of the car being struck? Explain.

_________________________________
_________________________________
_________________________________
_________________________________
_________________________________
TRIAL 1

Does the data support your hypothesis?

14 Perform another collision between the cars, but this time, measure their velocities.
   \( v_i \) – initial velocity before collision
   \( v_f \) – final velocity after collision (if using magnets, this is the same for both cars)

Example Graph
Striking Car

Example Graph
Car Being Struck

<table>
<thead>
<tr>
<th>( m )</th>
<th>( v_i )</th>
<th>( v_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
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</tbody>
</table>

15 Now calculate each car’s momentum and kinetic energy.

**Striking Car**

\[
\begin{array}{c|c|c}
\text{Momentum} p & \text{Initial Momentum} p_i & \text{Final Momentum} p_f \\
\text{Kinetic Energy} K & \text{Initial Kinetic Energy} K_i & \text{Final Kinetic Energy} K_f \\
\end{array}
\]

**Car Being Struck**

\[
\begin{array}{c|c|c}
\text{Momentum} p & \text{Initial Momentum} p_i & \text{Final Momentum} p_f \\
\text{Kinetic Energy} K & \text{Initial Kinetic Energy} K_i & \text{Final Kinetic Energy} K_f \\
\end{array}
\]

16 Finally, calculate the momentum and kinetic energy of the system.

To find the momentum of the system, add the momentum of its parts (the cars).
Do the same for kinetic energy.

**System Momentum**

\[
\begin{array}{c|c|c}
\text{Initial System Momentum} p_i & \text{Final System Momentum} p_f \\
\end{array}
\]

**System Kinetic Energy**

\[
\begin{array}{c|c|c}
\text{Initial System Kinetic Energy} K_i & \text{Final System Kinetic Energy} K_f \\
\end{array}
\]

17 Does the data support your hypothesis from Step 13? Explain.

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________
CONSERVATION OF MOMENTUM

Your data should have shown little change in the system’s momentum.

As long as there’s no external force, a system’s momentum should be conserved during a collision. The total momentum should not change. This is called the Conservation of Momentum, and it comes from Newton’s Laws (shown on p. 6).

18 Find the percent change for the system’s momentum in Trial 1.

\[
\text{% Change} = \frac{p_f - p_i}{p_i} \times 100\%
\]

19 Does the data from Trial 1 support Conservation of Momentum? Reference the percent change in your explanation.

CONSERVATION OF ENERGY

Your data probably showed the system’s kinetic energy decrease, and that’s OK.

In a collision, kinetic energy can be conserved or transformed into other forms of energy. Collisions are divided into three categories.

Elastic Collisions
If the kinetic energy of a system is conserved during a collision, the collision is elastic.

Inelastic Collisions
If the kinetic energy of a system is not conserved during a collision, the collision is inelastic.

Completely Inelastic Collisions
If the colliding objects stick together after the collision, the collision is completely inelastic.

20 Find the percent change for the system’s kinetic energy in Trial 1.

\[
\text{% Change} = \frac{K_f - K_i}{K_i} \times 100\%
\]

21 Was the collision from Trial 1 elastic, inelastic, or completely inelastic? Explain.
Wonder how momentum comes from Newton’s Laws? Here’s the math!

Let’s start by looking at Newton’s Second “Law,” \( F = ma \). If we do some algebra, this Law can give us information about momentum – we just need to make \( mv \) show up in the equation.

\[
\begin{align*}
F &= ma \\
F &= m \frac{v_f - v_i}{t} \\
Ft &= m(v_f - v_i) \\
Ft &= mv_f - mv_i \\
Ft &= p_f - p_i \\
Ft &= \Delta p
\end{align*}
\]

So force multiplied by time, \( Ft \), gives us the change in momentum, \( \Delta p \), (called impulse).

When your cars collide, they exert equal and opposite forces on each other (Newton’s 3rd “Law”), so the force of car 1 on car 2 equals the force of car 2 on car 1.

\[
\begin{align*}
F_{1 \ on \ 2} &= -F_{2 \ on \ 1} \\
F_{1 \ on \ 2}t &= -F_{2 \ on \ 1}t \\
\Delta p_1 &= -\Delta p_2 \\
\Delta p_1 + \Delta p_2 &= 0 \\
\Delta p_{\text{system}} &= 0
\end{align*}
\]

The cars exert forces on each other for the same amount of time.

This is the relationship we found from Newton’s Second “Law.”

Our system is the two cars. So if you add the change in momentum for both cars, you get the change of the system.

So using Newton’s Laws, we see that the momentum of a system does not change during a collision inside that system.
TRIAL 2

What if the striking car has more mass?

22 Secure weights to the striking car to increase its mass, then perform another trial. 100 to 200 g of weights is recommended (3.5 to 7.0 oz).

<table>
<thead>
<tr>
<th>Striking Car</th>
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</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>$m$</td>
</tr>
<tr>
<td>$v_i$</td>
<td>$v_i$</td>
</tr>
<tr>
<td>$v_f$</td>
<td>$v_f$</td>
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<tr>
<td>$p_i$</td>
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</table>

**System Momentum**

<table>
<thead>
<tr>
<th>$p_i$</th>
<th>$p_f$</th>
<th>% Change</th>
</tr>
</thead>
</table>

TRIAL 3

What if the car being struck has more mass?

23 Transfer the weights from the striking car to the car being struck, then perform the final trial.

<table>
<thead>
<tr>
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<tbody>
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</table>
CONCLUSION

24 Overall, does your data confirm the conservation of momentum? Justify your answer.

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_________________________________________________________________________
_________________________________________________________________________

25 Did changing the mass of either car affect the conservation of momentum?

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_________________________________________________________________________
_________________________________________________________________________

26 What were some sources of error for your measurements?

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

27 Were any of your collisions elastic? If not, which was the closest to being elastic and why?

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_________________________________________________________________________
_________________________________________________________________________

28 When your cars collided inelastically, what happened to the kinetic energy? Be specific.

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

29 Fill in the blanks below.

Both momentum and kinetic energy are calculated using ____________ and ____________.
Momentum is a ____________ quantity, while kinetic energy is a ____________ quantity.
In a collision, ____________ is always conserved, while ____________ is not.